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# FINAL REPORT ON ELECTRONICS RESEARCH

# AT THE UNIVERSITY OF TEXAS AT AUSTIN

For the period April 1, 1989 through June 30, 1992



## JOINT SERVICES ELECTRONICS PROGRAM

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Submitted by Edward J. Powers

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This final report summarizes research carried out by nine faculty and approximately eighteen graduate students at The University of Texas at Austin under the auspices of the Joint Services Electronics Program. This research program consists of five research units in solid-state electronics, two in electromagnetics, and two in information electronics. Solid-state electronics includes work in growth of III-V compounds by MBE, epitaxial growth of III-V semiconductor surfaces, charge transport in novel device-structures and materials, femtosecond processes in III-V semiconductors, and heterostructure device development. Information electronics includes multisensor signal processing, and nonlinear estimation and stochastic adaptive control. Research in electromagnetics involves millimeter wave active guided wave structures, and nonlinear wave phenomena.

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# OVERVIEW

# I. OVERVIEW

This Final Report summarizes research conducted under the auspices of AFOSR F49620-89-C-0044 and covers the thirty-nine month period ranging from April 1, 1989 through June 30, 1992. Nine faculty members and approximately eighteen graduate students from the Department of Electrical and Computer Engineering and the Department of Physics conducted the research described in this report. The University of Texas DoD JSEP program is a broad-based program with five research units in Solid State Electronics, two in Electromagnetics, and two in Information Electronics.

Solid State Electronics: Our work on the control of MBE growth has enhanced our ability to make accurately controlled quantum well structures and multilayer heterojunctions. We have used monolayer growth control to make and study resonant tunneling diodes, pseudomorphic modulation doped quantum wells, delta-doped structures, and distributed Bragg reflectors (DBRs). Our DBR work allows us to develop improved vertical cavity surface-emitting lasers (VCSELs) and also to examine details of optical phenomena in short-cavity lasers. We have used MBE regrowth techniques to provide current tunnelling into the device active region of the VCSEL. We use an AlAs/GaAs Bragg reflector for the n-side mirror, and a combination of AlAs/GaAs and either $ZnSe/CaF_2$ or $Si/SiO_2$ quarter-wave dielectric layers for the p-side mirror. We are finding excellent laser performance in terms of threshold current and lasing efficiency. Our DBRs are also being applied to novel optical detector structures.

We have already developed significant capability in the low temperature (250°C - 300°C) growth of undoped GaAs and $Al_{0.3}Ga_{0.7}As$ layers for high resistivity buffer and gate insulator applications. To evaluate the quality of subsequently grown epitaxial layers, quantum wells were grown on top of the LTG buffer layer and studied by low temperature photoluminescence. These experiments indicate that defects in the low temperature buffer do not migrate into epitaxial layers grown on top of the buffer. We should be able to use these layers to direct current to the active regions of our vertical cavity surface-emitting lasers, and similar applications may arise in the detector structures we intend to study in this work. The applications of LTG semi-insulating layers to optoelectronic devices and OEICs are of general interest because of the need for device integration with appropriate isolation.

We have developed Monte Carlo simulation capabilities which include multi-band electronic-hole scattering. We learned that such multi-band processes play a significant role in the energy loss rate of electrons to hole populations. We also learned that a failure to consider hole-overlap factors leads to a substantial overestimate of the energy loss rate of electrons to holes. We extended this simulator to a study of InP and InGaAs and included electron-hole scattering processes which involve the split-off band. This study developed the understanding that processes involving the split-off band are more important in InP than in InGaAs. We conducted a study of InP/InGaAs, InAlAs/InGaAs heterojunction bipolar transistor (HBT) base-collector structures in order to evaluate their potential for speed enhancement via the "extended overshoot" collector approach. Our studies verified that the extended overshoot collector demonstrates significant speed improvements for InGaAs collectors and indicated an apparent speed advantage of InP emitters. This advantage is due to the average energy at which carriers are injected into the base due to the band offset at the base/emitter heterojunction.

We have developed novel femtosecond laser/electron time-of-flight techniques, and used them to investigate rapid heating of electrons under laser excitation, laser induced thermionic emission, and electron lattice coupling and space charge effects in femtosecond photoexcitation processes at metal surfaces. We have also carried out a comprehensive analysis of time-of-flight instrumentation, including a significant advance in the understanding of the dynamical response of microchannel plate systems. With partial JSEP support, we have carried out the first inelastic electron scattering studies of surface phonons which explicitly test inelastic scattering selection rules and which also detect odd symmetry phonon modes.

New approaches to small signal femtosecond reflection and transmission spectroscopy of semiconductors have been developed - - intracavity frequency doubling, rapid scan data acquistion. Applications of these approaches include carrier dynamics in graphite, band renormalization processes in several semiconductors, two-photon spectroscopy of silicon. A second subpicosecond laser system has been acquired (AFOSR equipment grant), installed, and equipped for electro-optic sampling.

Electromagnetics: We have furthered the study of AlGaAs/GaAs quantum well injection transit (QWITT) diodes, and have achieved the highest peak-to-valley ratio for an AlGaAs/GaAs quantum well. A high peak current density of over 30 $kA/cm^2$ has been maintained for these diodes. GaAs/AlAs devices have been placed in an oscillator circuit designed for 10 GHz operation with an output of 1.2mW. We have also begun the study of quantum well diodes using AlAs/InGaAs grown on an InP substrate. We have tested a device with a quantum well formed by sandwiching a 47 Å $In_{0.53}Ga_{0.47}As$ well between 25 Å strained AlAs barriers. For this QWITT, at an oscillation frequency of about 3 GHz in an unoptimized circuit, an output of over 2 mW (20% dc to rf conversion efficiency) has been attained. The same device is able to produce high efficiency oscillation over a broad band by simply changing the rf circuit. To develop a monolithic tuning element, we have also built an optically controlled coplanar waveguide phase shifter using the epitaxial lift-off technique to mount the CPW's GaAs epilayer on a quartz substrate. This device has an extremely low loss to at least 40GHz, with very high optical sensitivity.

We have developed digitally implemented higher-order spectral analysis techniques that may be utilized to determine frequency-domain Volterra kernels up to third order. Furthermore, our approach is valid for random excitation of arbitrary amplitude statistics (nonGaussian or Gaussian) and arbitrary spectral density. This capability is unique and provides a powerful tool with which to investigate a wide variety of nonlinear physical phenomena, including four-wave interactions (a cubic effect). We have demonstrated how such an approach may be used to dectect "nonlinear signatures" in data, to quantify the strength of nonlinear wave interactions, and to quantify the nonlinear transfer of energy from various frequency bands in the excitation to other frequency bands in the response. Of particular note is the fact that we have published the first experimental estimates of nonlinear wave-wave coupling coefficients in turbulent media, where many such interactions are simultaneously occurring.

Information Electronics. We have made significant progress in the analysis and iterpretation of both mono-sensory and multi-sensory signals. This latter category includes signals sensed by similar as well as diverse sensors and which are analyzed concomitantly to provide useful information regarding the sensed scene and its characteristics. In the area of thermal and visual image synthesis, we have developed a prototype system for scene interpretation which relies on image segmentation and understanding the physics of individual sensors. Of particular interest is the ability to model nonhomogeneous 3D objects. Also noteworthy is the fusion of the three modalities associated with LADAR (range, intensity, velocity) with thermal imagery. The approach is to segment individual LADAR and thermal images into homogeneous regions first and to integrate the results from multiple segmentation maps into one. This final integrated segmentation provides the basis of image interpretation.

We have solved several fundamental open problems for adaptive estimation and control problems for stochastic systems involving incomplete (or noisy) observations of the state and unknown parameters. Motivated by problems in computer communication networks, we have solved and analyzed the first adaptive nonlinear estimation problem in the literature. We have begun to apply similar methods to adaptive stochastic control problems with incomplete observations; the first such problem we solved was one arising in the maintenance and quality control of a machine, production process, or network. We have also solved several problems in the area of discrete event systems (including flexible manufacturing systems and computer networks), in order to develop the capability for analyzing multi-level systems which can intelligently process different types of information.

Edward J. Powers
for the faculty and staff participants

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## PRINCIPAL INVESTIGATORS

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D. P. Neikirk, Associate Professor of Electrical and Computer Engineering

B. S. Streetman, Professor of Electrical and Computer Engineering

# DEGREES AWARDED

Andrew C. Campbell, August 1989, "Influence of the Silicon Donor (DX Center) and Growth Temperatures on GaAs/AlGaAs Heterostructures Grown by Molecular Beam Epitaxy."

Ananth Dodabalapur, August 1990, "Molecular Beam Epitaxial Growth and Correlation Between Electrical and Optical Properties of Modulation-Doped Quantum Wells."

Thomas R. Block, August 1991, "Photoluminescence and RHEED Studies of MBE Grown Materials and Structures."

Chong Koo An, May 1989, "Frequency Domain Analysis of Dual-Input/Multiple-Output Quadratic System with General Random Inputs."

Sang-Won Nam, December 1990, "Application of Higher-Order Spectral Analysis to Nonlinear System Identification."

Yongsoo Cho, May 1991, "Engineering Applications of Higher-Order Statistics and Volterra Models to Nonlinear Systems."

Kiho Kim, August 1991, "Time Domain Analysis of a Second-Order Volterra System with General Random Input with Applications to Nonlinear Physical Systems."

Won Tcheon Oh, May 1992, "Application of Higher-Order Statistics to Time Delay Estimation for Passive Sonar Systems."

**DEGREES AWARDED**

**M.S.**

Chanhee Oh, May 1989, "Integrated Modeling of Thermal and Visual Image Generation."

Sankaran Karthik, December 1989, "Modeling Non-homogeneous 3-D Objects For Thermal and Visual Image Synthesis."

Matthew G. Schneble, May 1991, "Feature Point Extraction and Correspondence Computation Among a Sequence of Real Images."

Chih-Wen Kuo, May 1989, "Characterization of coplanar waveguide discontinuities using the transverse resonance method."

Analib A. Chowdhury, May 1990, "Calculation of Superlattice Bandstructure: The Envelope Function Approximation."

Reaz Shaheed, December 1990, "Simulation of Heterojunction Bipolar Transistors Based on In-Alloy Material System."

Vijay Reddy, Spring 1990, "Molecular Beam Epitaxial Growth of AlAs/GaAs Double Barrier Resonant Tunneling Diodes."

Shiva Javalagi, Fall 1991, "High power and high efficiency quantun well diode oscillators."

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John Heston, Summer 1990, "Development of Twin Slot Antenna Structures for Millimeter Wave Imaging Applications."

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Su..n Foxworth, August 1990, "Modeling of Fields in Semiconductor Heterojunctions."

Y.C. Shih, May 1991, "Delta Doping in III-V Compound Semiconductors."

Anand Srinivasan, May 1992, "Molecular Beam Epitaxy of Low Temperature Gallium Arsenide."

Greg H. Leitich, August 1991, "A Two-Input/Single-Output Model of a Cubically Nonlinear System."

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